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CORPS OF ENGINEERS, U.S. ARMY

DESCRIPTION AND CLASSIFICATION OF FROZEN SOILS

Based Upon a Joint Effort of the Division of Building Research, National Research Council of Canada, and the Arctic Construction and Frost Effects Laboratory, U. S. Army Corps of Engineers

DRAFT

TECHNICAL REPORT NO. 75

Arctic Construction and Frost Effects Laboratory
U.S. Army Engineer Division, New England
Waltham, Massachusetts

for

Office of the Chief of Engineers
Civil Engineering Branch
Engineering Division
Military Construction

January 1961

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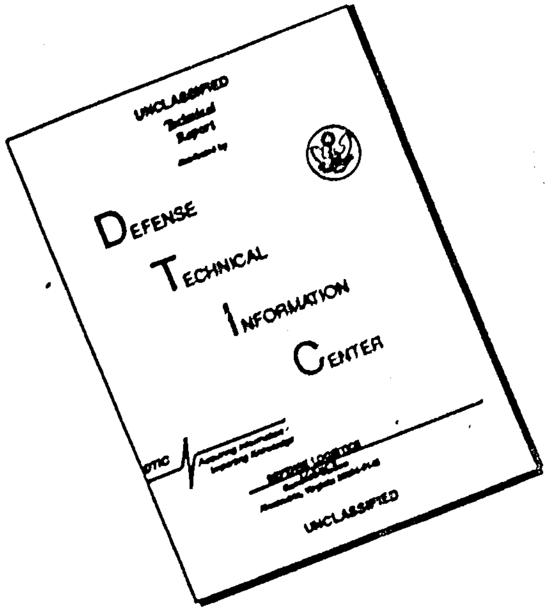

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PREFACE

The heart of the description and classification of frozen soils shown in columns (1) through (6) of Figure 2 of this report represents the joint efforts of representatives of the Building Research Division, National Research Council of Canada, and of the Arctic Construction and Frost Effects Laboratory, U. S. Army Engineer Division, New England. It is based on the experience of these organizations over several years with various forms of a system originally devised by the Arctic Construction and Frost Effects Laboratory in 1952.* The remainder of Figure 2, and of the report, is a contribution of the Arctic Construction and Frost Effects Laboratory.

This presentation is the product of a program of studies being conducted for the Chief of Engineers, Department of the Army, under the administrative direction of the Civil Engineering Branch, Engineering Division, Military Construction. The program is aimed at developing engineering criteria for design and construction in arctic and subarctic regions and in areas of seasonal frost.

*Published as Appendix A of Vol. 1 of "Investigation of Description, Classification and Strength Properties of Frozen Soils," by Arctic Construction and Frost Effects Laboratory, issued as Report 8 of U. S. Army Snow, Ice and Permafrost Research Establishment, June 1952.

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SYNOPSIS

The description and classification of frozen soils presented herein is an extension of the Unified Soil Classification System adopted by the U. S. Army Corps of Engineers and the U. S. Bureau of Reclamation in 1952. Descriptions, based on physical appearance, are non-genetic and are applicable to both naturally and artificially frozen soils. Field identification data pertaining to frozen soils and those pertinent properties of frozen materials which can be measured by physical tests are indicated. Also, guides are presented for construction on soils subject to freezing and thawing. The report includes photographic illustrations of frozen soil types; a chart showing relationships between unit dry weight of soil, water content, and ice volume; and an illustrative example of graphical presentation of frozen soil data.

INTRODUCTION

1. When the Unified Soil Classification System* is extended to classification of frozen soils, special expansion of the system is required in order to meet engineering and scientific needs for adequate and concise identification of the materials. Identification of seasonally frozen soil or permafrost according to structural divisions caused by freezing and thawing such as "suprapermafrost" or "annual frost zone," illustrated in Figure 1, provides no information on those factors of appearance and physical properties which are essential guides to the nature and behavior of the materials in the frozen state and to the changes which may occur upon thawing. Also, such identification is not applicable to specimens frozen in the laboratory. Therefore, a frozen soil description and classification system, which is independent of the geologic history or mode of origin of the material, is needed. This system should also be capable of easy expansion or contraction in order to provide any desired degree of detail. The system described herein affords these characteristics.

*Described in Technical Memorandum No. 3-357, U. S. Army Waterways Experiment Station, March 1953, with Appendixes A and B.

FEATURES OF THE FROZEN SOIL CLASSIFICATION SYSTEM

2. Parts of the System. The system for describing and classifying frozen soil is shown in Figure 2. As indicated in the first column of Figure 2, the frozen soil is identified in three steps, denoted as Parts I, II, and III. Under Part I the soil phase is identified independently of the frozen state; the Unified Soil Classification System is used, a summary of which is shown in Figure 3. Under Part II, the soil characteristics resulting from the frozen state of the material are added to the soil description. Under Part III, important ice strata found in the soil are described.

3. Classification of Frozen Soil - Major Groups. As shown in columns (2) and (3) of Figure 2, under Part II, frozen soils are divided into two major groups: soils in which segregated ice is not visible to the unaided eye (designation N), and soils in which segregated ice is visible (designation V). Since, as will be described below, ice layers exceeding 1 inch in thickness are identified separately, the latter major grouping is applied only to soil containing ice layers 1 inch or less in thickness.

4. Frozen soils in the N group will commonly, on inspection by the unaided eye, reveal the presence of ice within the soil voids by crystalline reflections or by a sheen on fractured or trimmed surfaces; however, the appearance is given that the water has frozen within the original voids in the soil, without segregation. Frozen soils in the V group give the opposite impression, and segregated ice is visible not merely as pin point crystalline reflections or a diffuse sheen but as separate ice inclusions of measureable dimensions.

5. Frozen Soils in which Segregated Ice is not Visible. As shown in columns (4) and (5) of Figure 2, materials in which segregated ice is not visible to the unaided eye (designation N) are divided into two types:

Nf (ice non-visible; friable). This is poorly bonded or friable material in which segregated ice is not visible to the unaided eye. This condition exists when the degree of saturation is low. This type of frozen soil is illustrated in photographs 1 and 2 of Figure 4.

Nb (ice non-visible; bonded). This is well bonded frozen soil in which the ice cements the material into a hard solid mass, but segregated ice is not visible to the unaided eye. Soils showing this characteristic are generally at a moderate to high degree of saturation. When at high degree of saturation, they may or may not contain substantial quantities of microscopic segregated ice. On basis of detailed examinations and tests this sub-group may be further divided into the following sub-categories:

Nbn (without excess ice). No segregated ice is present, either visible to the unaided eye or microscopic. This type of frozen soil is illustrated in photographs 1 and 3, Figure 4.

Nbe (contains excess ice, microscopic). This condition may occur in very fine silty sands or coarse silts where excess ice is present but is so uniformly distributed that it is not readily apparent to the unaided eye. Appreciable settlement may occur in such soils upon thawing. This type of frozen soil is illustrated in photograph 4, Figure 4.

6. Frozen Soils in which Ice is Visible. The soils in which significant segregated ice is visible to the unaided eye (designation V) are divided into the following four sub-groups, arranged approximately in sequence of increasing ice content as commonly encountered:

Vx (ice visible as individual ice crystals or inclusions)

Vc (ice visible as ice coatings on particles)

Vr (ice visible as random or irregularly oriented ice formations)

Vs (ice visible as stratified or distinctly oriented ice formations)

The Vx type of frozen soil is shown in photograph 5, Figure 4; Vr types of frozen soils are illustrated in photographs 6 and 7, Figure 5, and Vs types in photographs 8, 9, and 10, Figure 5.

7. Description of Substantial Ice Strata. Referring to columns (2) and (3) of Figure 2 under Part III, substantial ice strata greater than 1 inch in thickness are designated separately as ICE. As shown in columns (4) and (5) of Figure 2, the identification may fall into either of the following two broad categories:

Ice Plus Soil Type (ice with soil inclusions)

Ice (ice without soil inclusions)

8. Identification and Description. Field identification guidance is presented in column (6) of Figure 2. In addition to determination of major group and sub-group in accordance with columns (2) through (5) of Figure 2, additional descriptive terms and data may be used as indicated therein.

Some of the soils found in permafrost regions may also be described in exploration logs by special terms (such as "muskeg") for additional clarification.

9. When more than one sub-group characteristic is present in the same material, multiple sub group designations may be used, as Vs, r. Photograph 2, Figure 4, shows an example of frozen soil of the latter type.

10. When greater detail and more specific information is desired than is obtainable from visual inspection, physical tests and measurements may be performed on the frozen soil as indicated in column (7) of Figure 2. A camera, a small-power hand magnifying lens, and pint-size graduated jars should be standard items of field equipment for soil and survey crews. To obtain a rough estimate of the possible presence of excess ice, a simple field test can be made by placing a lump of frozen soil in a jar, allowing it to melt and visually observing the relative volume of supernatant or free water standing above the soil after the lump has melted. By initially performing this test with specimens of known ice content, a basis for field judgement can be established. Since proportions of ice and soil may vary widely, it may sometimes be difficult to decide without such a test whether a given material falls, for example, in the category of frozen soil or of ice with soil inclusions. Material containing as much as 80 percent of ice by volume and only 20 percent soil can sometimes give the appearance of being mostly soil. When more exact evaluation of presence of excess ice is required, specimens may be thawed in the laboratory in consolidometers or rubber membranes, or material may be thawed in place in the field.

11. Only needed portions of the detail and descriptive material outlined in columns (4) through (7) of Figure 2 should be used. In many of the simpler engineering applications, only a few of the most important elements need be recorded. For some investigations it may be satisfactory to use the Nb designation without breakdown into Nbn or Nbe categories. In other applications it might even be sufficient to use only the N and V major group designations, to indicate whether or not segregated ice is visible. On the other hand, in many scientific studies very detailed records may be necessary.

12. Thaw Characteristics. For engineering purposes, it is of very great importance to known whether significant settlement will take place upon thawing of the frozen soil. If the amount of ice present will produce more water upon melting than can be held in the voids of the soil, then the material is thaw-unstable to a degree that is dependent upon the amount of the excess ice and the soil density. If all the melt water can be absorbed by the soil voids without significant settlement, then the soil can be considered thaw-stable. Columns (8) and (9) of Figure 2 present guides for construction on soils subject to freezing and thawing. The thaw characteristics shown in column (8) are particularly significant. Frozen soils designated as Nf and Nbn are usually thaw-stable, that is, no detrimental settlement of structures would normally be anticipated if thawing occurred. Frozen soils in all other sub-groups are potentially thaw-unstable and significant settlement of structures founded thereon may occur.

13. Frozen open-work gravel is a special type of material which often proves difficult to evaluate as to its thaw-settlement potential. Although substantial amounts of pure ice are apparent in the voids of such material, sufficient point contacts between particles may exist to limit settlement on thaw to minor amounts. In critical cases, field thaw-settlement tests, using loaded plates and steam thawing, may be necessary.

14. Frozen bedrock does not always provide a thaw-safe foundation. Therefore, when bedrock is encountered in subfreezing temperatures, careful observations should be made to determine the quantity and mode of occurence of all ice formations in bedding planes, fissures, or other spaces.

ICE OR WATER CONTENT OF FROZEN SATURATED SOILS

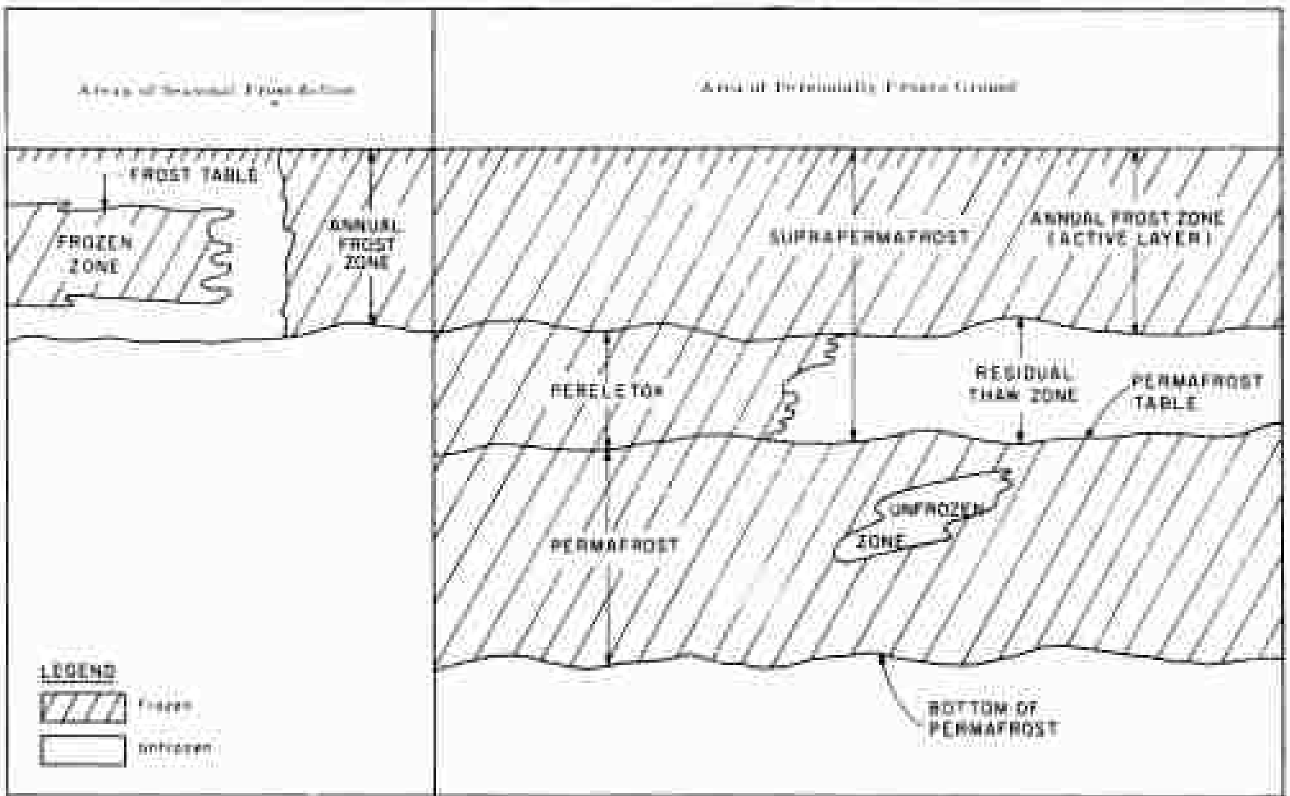
15. In considerations involving frozen soils, the generally prevailing conditions include complete saturation of the soil phase and all of the water frozen. For these conditions, and assuming a specific gravity of the soil particles of 2.70, the relationships between the unit dry weight of soil, water content, and ice volume are shown in Figure 6. This chart may be used by designers or field engineers for rapid estimation of the relationships between these variables. Use of the chart is indicated by the following example and illustrated by lines and arrows on Figure 6. Assume a specimen of frozen silt with excess ice estimated at approximately 60 percent. Based on the appearance of the silt layers in the core, it is estimated that the normal dry unit weight of the silt is fairly high, say 95 pcf. The chart is then entered at 95 pcf on the left and a horizontal line is extended to the

intersection of the sloping 60 percent excess ice line. The total porosity, n, which in this case equals the proportion of ice volume of the total specimen, is then observed on the scale at the bottom of the plot (77 percent). The intersection of the vertical line (77 percent porosity) with the 100 percent saturation line indicates on the left-side scale the equivalent overall dry unit weight of the frozen specimen, i.e., 38 pcf. The curve in Figure 6 marked "Percent Volume of Ice vs Water Content" shows the relationship between the water content of a frozen specimen and total volume of ice or porosity, n. For a porosity of 77 percent in the above example, the water content indicated by the right-side scale would be approximately 114 percent.

GRAPHICAL PRESENTATION OF SOILS DATA

16. It is customary to present the results of soils explorations on drawings as schematic representations of the borings or test pits, with the various soils encountered shown by appropriate symbols. The recommended procedure for graphical presentation of frozen soil classification consists of showing the applicable letter symbols for the soil phase in accordance with the Unified Soil Classification System for unfrozen soils, followed by the frozen soil designation. An illustrative example of the use of the frozen soil classification system in a typical exploration log is shown in Figure 7. For the purpose of readily identifying the frozen soil zones, a wide line is drawn down the left side of the graphic log of the exploration within the range that the frozen material occurs.

ILLUSTRATIONS OF TERMINOLOGY USED TO IDENTIFY
CHARACTERISTIC STRUCTURAL CLASSIFICATIONS OR
SOIL FEATURES IN AREAS OF FROZEN GROUND



Definitions* of Soil and Other Terms Relating to Frozen Ground Areas

Annual frost zone (active layer). The top layer of ground subject to annual freezing and thawing. In arctic and subarctic regions where annual freezing penetrates to the permafrost table, suprapermafrost and the annual frost zone are identical.

Excess ice. Ice in excess of the fraction which would be retained as water in the soil voids upon thawing.

Frost table. The surface, usually irregular, which represents the penetration, at any time in spring and summer, of thawing of the seasonal frozen ground.

Frozen zone. A range of depth within which the soil is frozen. The frozen zone may be bound both top and bottom by unfrozen soil, or at the top by the ground surface.

Ground ice. A body of more or less clear ice within frozen ground.

Ice wedge. A wedge-shaped ice mass in permafrost, usually associated with fissure polygons.

Icing. A surface ice mass formed by freezing of successive sheets of water.

Muskeg. Poorly drained organic terrain consisting of a mat of vegetation overlying peat of varying thickness, from a few inches to many feet.

Permafrost. Perenially frozen ground.

Permafrost table. The surface which represents the upper limit of permafrost.

Pereletok. A frozen layer at the base of the active layer which remains unthawed for one or two summers.

Residual thaw zone. A layer of unfrozen ground between the permafrost and the annual frost zone. This layer does not exist where annual frost extends to permafrost.

Suprapermafrost. The entire layer of ground above the permafrost table.

*For more complete list of definitions, see Hennion, F., Frost and Permafrost Definitions, Highway Research Board Bulletin 111, 1955.

FIGURE 1

DESCRIPTION AND CLASSIFICATION OF FROZEN SOILS

PART I								
DESCRIPTION OF SOIL PHASE (Independent of Frozen State)	Classify Soil Phase by the Unified Soil Classification System							

	Major Group: Description (1)	Major Group: Designation (2)	Sub-group: Description (4)	Sub-group: Designation (5)	Field Identification (6)	Pertinent Properties of Frozen Materials Which May be Measured by Physical Tests to Supplement Field Identification (7)	Guide for Construction on Soils Subject to Freezing and Thawing: Thaw Characteristics (8)	Guide for Construction on Soils Subject to Freezing and Thawing: Criteria (9)
PART II DESCRIPTION OF FROZEN SOIL	Segregated ice not visible by eye	N	Poorly bonded or friable	Nf	Identify by visual examination. To determine presence of excess ice, use procedure under note (c) below and hand magnifying lens as necessary. For soils not fully saturated, estimate degree of ice saturation: Medium, Low. Note presence of crystals, or of ice coatings around larger particles.	In-Place Temperature Density and Void Ratio a. In Frozen State b. After Thawing in Place Water Content (total H_2O including ice) a. Average b. Distribution Strength a. Compressive b. Tensile c. Shear d. Adfreeze Elastic Properties Plastic Properties Thermal Properties Ice Crystal Structure (using optical instruments) a. Orientation of Axes b. Crystal Size c. Crystal Shape d. Pattern of Arrangement	Usually thaw-stable	The potential intensity of ice segregation in a soil is dependent to a large degree on its void sizes and for pavement design purposes may be expressed as an empirical function of grain size as follows: Most inorganic soils containing 3 percent or more of grains finer than 0.02 mm in diameter by weight are frost-susceptible for pavement design purposes. Gravels, well-graded sands and silty sands, especially those approaching the theoretical maximum density curve, which contain 1½ to 3 percent finer than 0.02 mm by weight should be considered as possibly frost-susceptible and should be subjected to a standard laboratory frost-susceptibility test to evaluate their behavior during freezing. Uniform sandy soils may have as much as 10 percent of grains finer than 0.02 mm by weight without being frost-susceptible. However, their tendency to occur interbedded with other soils usually makes it impractical to consider them separately.
			Well bonded: No excess ice	Nb n				
			Well bonded: Excess ice	Nb e				
	Segregated ice is visible by eye (ice 1 inch or less in thickness)	V	Individual ice crystals or inclusions	Vx	For ice phase, record the following as applicable: Location Orientation Thickness Length Spacing Hardness Structure (per Part III below) Color Size Shape Pattern of arrangement		Usually thaw-unstable	Soils classed as frost-susceptible under the above pavement design criteria are likely to show significant ice segregation and frost heave if frozen at normal rates with free water readily available. Soils so frozen will fall into the thaw-unstable category. However, they may also be classed as thaw-stable if frozen without access to sufficient water to permit ice segregation. Soils classed as non-frost-susceptible under the above criteria usually occur without significant ice segregation and are usually thaw-stable for pavement applications. However, the criteria are not exact and may be inadequate for some structure applications. Exceptions may also result from minor soil variations. In permafrost areas, ice wedges, pockets, veins, or other ice bodies may be found whose mode of origin is different from that described above. Such ice may be the result of cracking of the surface by thermal expansion and contraction or phenomena or may be glacial or other ice which has been buried under a protective earth cover.
			Ice coatings on particles	Vc				
			Random or irregularly oriented ice formations	Vr				
			Stratified or distinctly oriented ice formations	Vs	Estimate volume of visible segregated ice present as percent of total sample volume.			
PART III DESCRIPTION OF SUBSTANTIAL ICE STRATA	Ice (Greater than 1 inch in thickness)	ICE	Ice with soil inclusions	Ice + soil type	Designate material as ICE (d) and use descriptive terms as follows, usually one item from each group, as applicable: Hardness: HARD, SOFT (of mass, not individual crystals) Structure: CLEAR, CLOUDY, POROUS, CANDLED, GRANULAR, STRATIFIED Color (Examples): COLORLESS, GRAY, BLUE Admixtures (Examples): CONTAINS FEW THIN SILT INCLUSIONS	Same as Part II above, as applicable, with special emphasis on Ice Crystal Structure.		
			Ice without soil inclusions	Ice				

DEFINITIONS:

Ice Coatings on Particles are discernible layers of ice found on or below the larger soil particles in a frozen soil mass. They are sometimes associated with hoarfrost crystals, which have grown into voids produced by the freezing action.

Ice Crystal is a very small individual ice particle visible in the face of a soil mass. Crystals may be present alone or in a combination with other ice formations.

Clear Ice is transparent and contains only a moderate number of air bubbles. (e)

Cloudy Ice is relatively opaque due to entrained air bubbles or other reasons, but which is essentially sound and non-pervious. (e)

Porous Ice contains numerous voids, usually interconnected and usually resulting from melting at air bubbles or along crystal interfaces from presence of salt or other materials in the water, or from the freezing of saturated snow. Though porous, the mass retains its structural unity.

Candled Ice is ice which has rotted or otherwise formed into long columnar crystals, very loosely bonded together.

Granular Ice is composed of coarse, more or less equidimensional, ice crystals weakly bonded together.

Ice Lenses are lenticular ice formations in soil occurring essentially parallel to each other, generally normal to the direction of heat loss and commonly in repeated layers.

Ice Segregation is the growth of ice as distinct lenses, layers, veins, and masses in soils, commonly but not always oriented normal to direction of heat loss.

Well-bonded signifies that the soil particles are strongly held together by the ice and that the frozen soil possesses relatively high resistance to chipping or breaking.

Poorly-bonded signifies that the soil particles are weakly held together by the ice and that the frozen soil consequently has poor resistance to chipping or breaking.

Friable denotes extremely weak bond between soil particles. Material is easily broken up.

Thaw-Stable frozen soils do not, on thawing, show loss of strength below normal, long-time thawed values nor produce detrimental settlement.

Thaw-Unstable frozen soils show, on thawing, significant loss of strength below normal, long-time thawed values and/or significant settlement, as a direct result of the melting of the excess ice in the soil.

NOTES:

(a) When rock is encountered, standard rock classification terminology should be used.

(b) Frozen soils in the N group may, on close examination, indicate presence of ice within the voids of the material by crystalline reflections or by a sheen on fractured or trimmed surfaces. However, the impression to the unaided eye is that none of the frozen water occupies space in excess of the original voids in the soil. The opposite is true of frozen soils in the V group.

(c) When visual methods may be inadequate, a simple field test to aid evaluation of volume of excess ice can be made by placing some frozen soil in a small jar, allowing it to melt and observing the quantity of supernatant water as a percent of total volume.

(d) Where special forms of ice, such as hoarfrost, can be distinguished, more explicit description should be given.

(e) Observer should be careful to avoid being misled by surface scratches or frost coating on the ice.

NOTES:

The letter symbols shown are to be affixed to the Unified Soil Classification letter designations, or may be used in conjunction with graphic symbols in the preparation of logs or geological profiles. Example – a lean clay with essentially horizontal ice lenses:

$\boxed{\text{CL-Vs}}$ or $\boxed{\text{Vs}}$

The descriptive name of the frozen soil type and a complete description of the frozen material are the fundamental elements of this classification scheme. Additional descriptive data should be added where necessary. The letter symbols are secondary and are intended only for convenience in preparing graphical presentations. Since it is frequently impractical to describe ice formations in frozen soils by means of words alone, sketches and photographs should be used where appropriate to supplement descriptions.

The abbreviation NFS is commonly used to designate non-frost-susceptible materials in exploration logs and drawings.

January [illegible]

Arctic Construction and Frost Effect Laboratory, U.S. Army Engineer Division, New England, Waltham, Mass.

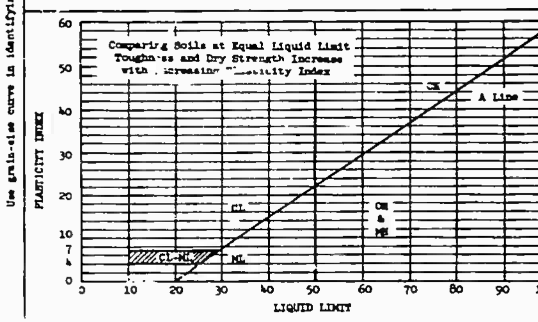
FIGURE 2

UNIFIED SOIL CLASSIFICATION
(Including Identification and Description)

Major Divisions (1)	Major Divisions (2)		Group Symbols (3)	Typical Names (4)	Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights) (5)			Information Required for Describing Soils (6)	Laboratory Classification Criteria (7)
Coarse-grained Soils More than half of material is larger than No. 200 sieve size. The No. 200 sieve size is about the smallest particle visible to the naked eye.	Gravels More than half of coarse fraction is larger than No. 4 sieve size. (For visual classification, the 1/4-in. size may be used as equivalent to the No. 4 sieve size)	Clean Gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.			For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions, and drainage characteristics.	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.				Not meeting all gradation requirements for GW
		Gravels with Fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixture.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).			Give typical name; indicate approximate percentages of sand and gravel, maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses.	Atterberg limits below "A" line or PI less than 4 — Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures see CL below).				Atterberg limits above "A" line with PI greater than 7
	Sands More than half of coarse fraction is smaller than No. 4 sieve size.	Clean Sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines.	Wide range in grain size and substantial amounts of all intermediate particle sizes.				$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
			SP	Poorly graded sands or gravelly sands, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing.				Not meeting all gradation requirements for SW
		Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).			Example: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2-in. maximum size; rounded and subangular sand grains, coarse to fine; about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM).	Atterberg limits below "A" line or PI less than 4 — Limits plotting in hatched zone with PI between 4 and 7 are borderline cases requiring use of dual symbols.
			SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures see CL below).				Atterberg limits above "A" line with PI greater than 7
Fine-grained Soils More than half of material is smaller than No. 200 sieve size.					Identification Procedures on Fraction Smaller than No. 40 Sieve Size: Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)		
	Silts and Clays Liquid limit is less than 50		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	None to slight	Quick to slow	None	For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions.	
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to very slow	Medium		
			OL	Organic silts and organic silty clays of low plasticity.	Slight to medium	Slow	Slight	Give typical name; indicate degree and character of plasticity; amount and maximum size of coarse grains; color in wet condition; odor, if any; local or geologic name and other pertinent descriptive information; and symbol in parentheses.	
	Silts and Clays Liquid limit is greater than 50		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Slight to medium	Slow to none	Slight to medium		
			CH	Inorganic clays of high plasticity, fat clays.	High to very high	None	High		
			OH	Organic clays of medium to high plasticity, organic silts.	Medium to high	None to very slow	Slight to medium	Example: Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML).	
Highly Organic Soils			Pt	Peat and other highly organic soils.	Readily identified by color, odor, spongy feel and frequently by fibrous texture.				

Use grain-size curve in identifying the fractions as given under field identification.

Determine percentages of gravel and sand from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse-grained soils are classified as follows:
Less than 5% GW, GP, SW, SP.
More than 12% GM, GC, SM, SC.
5% to 12% Borderline cases requiring use of dual symbols.



PLASTICITY CHART

For laboratory classification of fine-grained soils

(1) Boundary classifications: Soils possessing characteristics of two groups are designated by combinations of group symbols. For example GW-GC, well-graded gravel-sand mixture with clay binder. (2) All sieve sizes on this chart are U. S. standard.

FIELD IDENTIFICATION PROCEDURES FOR FINE-GRAINED SOILS OR FRACTIONS

These procedures are to be performed on the minus No. 40 sieve size particles, approximately 1/64 in. For field classification purposes, screening is not intended, simply remove by hand the coarse particles that interfere with the tests.

Dilatancy (reaction to shaking)

After removing particles larger than No. 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (crushing characteristics)

After removing particles larger than No. 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun, or air-drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

Toughness (consistency near plastic limit)

After particles larger than the No. 40 sieve size are removed, a specimen of soil about one-half inch cube in size, is molded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one-eighth inch in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line.

Highly organic clays have a very weak and spongy feel at the plastic limit.

Adopted by Corps of Engineers and Bureau of Reclamation, January 1952

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FIGURE 3

Photograph 1

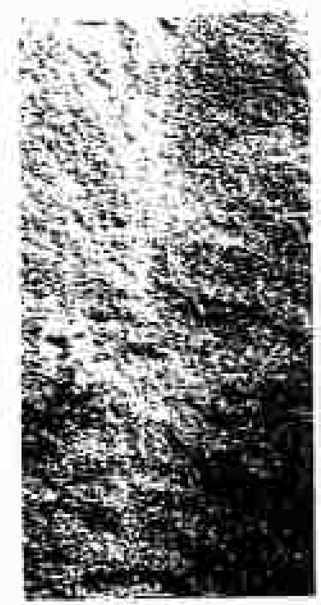
Frozen fine SILT. Top portion well-bonded, saturated.
Classification: ML, Nbn

Bottom portion friable.
Classification: ML, Nf

Photograph 2

Frozen lean CLAY. Ice lenses in top portion formed from moisture drawn from below.
Classification: CL, Vs,r

Bottom portion medium bonded and somewhat friable.
Classification: CL, Nf



Photograph 3

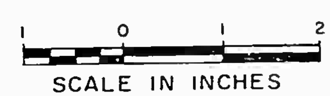
Frozen, well-graded silty SAND. Well-bonded.
Classification: SM, Nbn

Photograph 4

Frozen fine SAND. Well-bonded, high degree of saturation.
Classification: SM, Nbe

Photograph 5

Frozen, clayey sandy GRAVEL with ice coatings on numerous stones.
Classification: GW-GC, Vc



PHOTOGRAPHS OF FROZEN SOIL TYPES

FIGURE 4

Photograph 6

Frozen, clayey, gravelly SAND with considerable irregular ice segregation.
Classification: SM, Vr

Photograph 7

Upper Portion: Frozen clayey SILT with occasional stones.
Classification: ML-CL, Vr
Lower Portion: ICE, irregular, up to 2-inches thick, and containing some silt inclusions.

Photograph 8

Frozen lean CLAY with stratified ice lenses.
Classification: CL-OL, Vs

Photograph 9

Frozen lean CLAY with stratified ice lenses.
Classification: CL, Vs

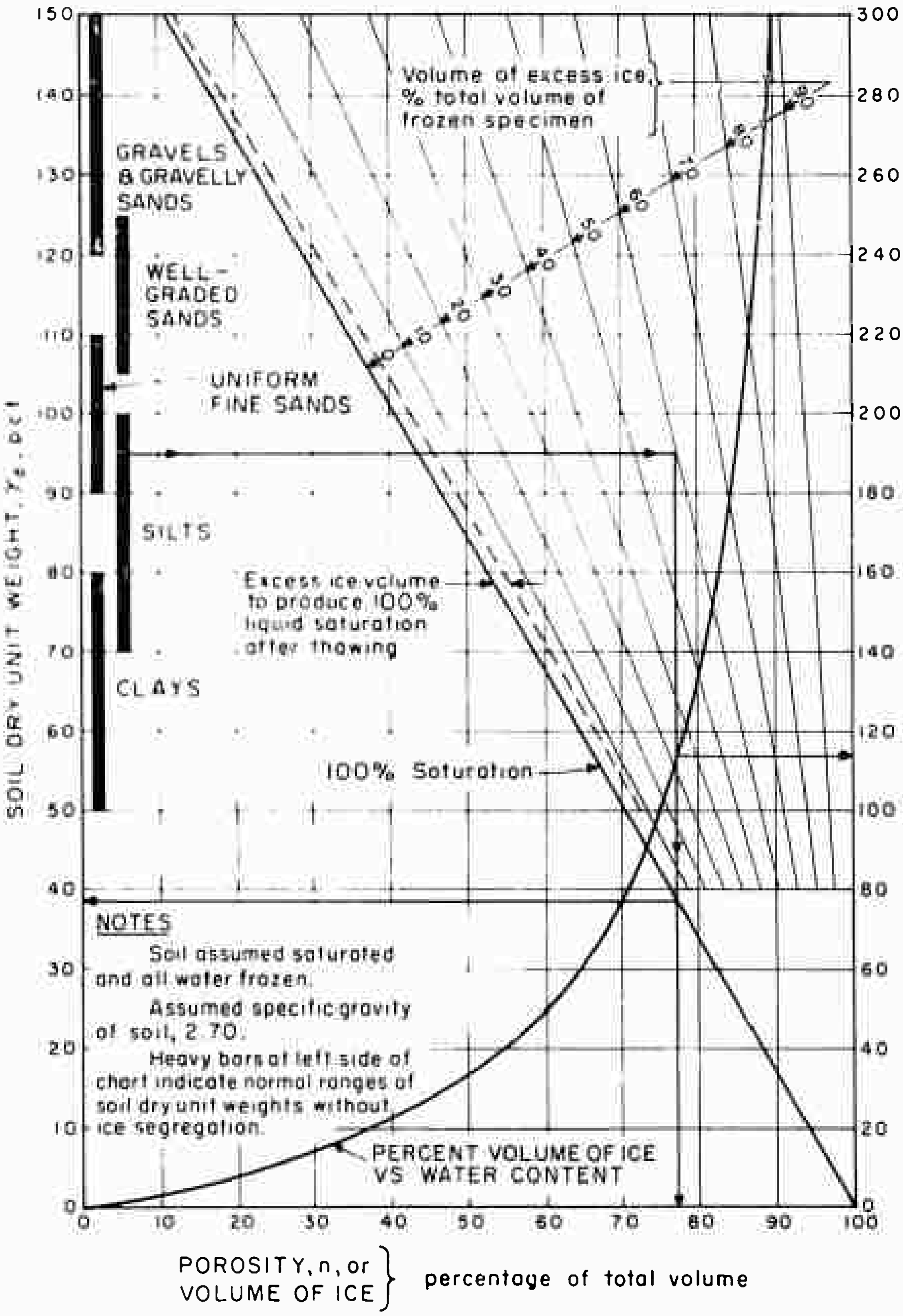
Photograph 10

Upper Portion: Frozen silty CLAY, with stratified ice lenses.
Classification: CL, Vs
Lower Portion: ICE with numerous clay inclusions. (Total ice volume approx. 87%).

SCALE IN INCHES

PHOTOGRAPHS OF FROZEN SOIL TYPES

FIGURE 5



SOIL DRY UNIT WEIGHT, ICE VOLUME, AND WATER CONTENT RELATIONSHIPS

FIGURE 6

ILLUSTRATIVE EXAMPLE OF THE USE OF
THE FROZEN SOIL CLASSIFICATION SYSTEM
IN TYPICAL EXPLORATION LOG

Surface Elevation 963.2 ft

DEPTH IN FEET		
0.0	OL	Organic SANDY SILT, not frozen.
0.5	GW	Brown, well-graded SANDY GRAVEL medium compact, moist, not frozen.
1.8	GW, Nf	Brown, well-graded SANDY GRAVEL, frozen, no visible segregation, negligible thin ice film on gravel sizes and within larger voids, poorly bonded.
3.7	GW, Nbn	Brown, well-graded SANDY GRAVEL, frozen, no visible segregation, well bonded.
5.4	ML, Vs	Black, micaceous SANDY SILT, frozen, stratified horizontal ice lenses averaging 4 inches in horizontal extent, hairline to 1/4 inch in thickness, 1/2 to 3/4 inch spacing. Visible ice = 20 ± % of total volume. Ice lenses hard, clear, colorless.
7.7	ICE	ICE, hard, slightly cloudy, colorless, few scattered inclusions of silty sand.
9.1	PT, Vr	Dark brown PEAT, frozen, well bonded, high degree of saturation. 5% visible ice.
10.5	MH, Vr	Light brown SILT, frozen, irregularly oriented ice lenses and layers 1/4 to 3/4 inch thick on random pattern grid approx. 3 to 4 inch spacing. Visible ice = 10 ± % of total volume. Ice moderately soft, porous, gray-white.
14.3		Bedrock. Laminated shale. Top few feet weathered. 1/16" thick ice lenses in fissures to 16.0'. None below.
20.6		Bottom of exploration

FIGURE 7